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A Validation of the Spatial Variant of the Sternberg Memory Search Task: Search Rate, Response Hand & Task Interference

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A series of three experiments are reported that examine the spatial and verbal variants of the Sternberg Memory Search Task and their relation to dual task interference. The verbal task employs 25 letters of the alphabet as stimuli, the spatial task, 25 randomly positioned 5-dot matrices. These had been previously employed in investigations by Micalizzi and Wickens (spatial), Wickens and Derrick (verbal), and Wickens and Sandry (both). In experiment 1, the effect of memory set size (1, 2, and 4) on the slope of the

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Sternberg function of both stimulus types was compared. Both produced generally linear functions, although there was a suggestion of a weak quadratic term in the function of the spatial stimuli. A reliable interaction between stimulus type, memory set size, and response hand provided evidence for the hemispheric separation of processing of the two stimulus types, and for resource competition within hemispheres. The slope of the function was significantly greater for the spatial stimuli.

In experiment 2, a memory search task with each of the two stimulus sets was performed concurrently with a highly verbal task (short term memory of low imagry words) and a hypothesized spatial task (tracking). The pattern of interference observed in the four task combinations confirmed the spatial-verbal dichotomy as an important one in accounting for variance in dual task interference. In experiment 3, the two search tasks were time-shared with a perceptual task in which subjects monitored an autopilot-controlled dynamic system for intermittent failures,(discrete changes in the transfer function). Greater interference was found with the spatial than the verbal variant of the Sternberg task, suggesting that the failure detection task is spatial in nature. However, the results failed to indicate the presence of an interaction between dual task load and memory set size, with either variant of the Sternberg task. These results are consistent with other experimental studies in which the memory set size variable fails to interact with the presence or absence of a primary task. The results of all three experiments are discussed as they pertain to the importance of the spatial/verbal dichotomy of tasks, in the design of systems where time-sharing is required, and in the assessment of operator workload.

Abstract

A series of three experiments are reported that examine the spatial and verbal variants of the Sternberg Memory Search Task and their relation to dual task interfernce. The verbal task employs 25 letters of the alphabet as stimuli, the spatial task, 25 randomly positioned 5-dot matrices. These had been previously employed in investigations by Micalizzi and Wickens (spatial), Wickens and Derrick (verbal), and Wickens and Sandry (both). In experiment 1, the effect of memory set size (1, 2, and 4) on the slope of the Sternberg function of both stimulus types was compared. Both produced generally linear functions, although there was a suggestion of a weak quadratic term in the function of the spatial stimuli. A reliable interaction between stimulus type, memory set size, and response hand provided evidence for the hemispheric separation of processing of the two stimulus types and for resource competition within hemispheres. The slope of the function was significantly greater for the spatial stimuli.

In experiment 2, a memory search task with each of the two stimulus sets was performed concurrently with a highly verbal task (short term memory of low imagry words) and a hypothesized spatial task (tracking). The pattern of interference observed in the four task combinations confirmed the spatial-verbal dichotomy as an important one in accounting for variance in dual task interference. In experiment 3, the two search tasks were time-shared with a perceptual task in which subjects monitored an autopilot-controlled dynamic system for intermittent failures, (discrete changes in the transfer function). Greater interference was found with the spatial than the verbal variant of the Sternberg task, suggesting that the failure detection task is spatial in

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Introduction

The efficiency of dual task performance may be influenced by a number of variables such as the difficulty of task, the level of practice of the individual, and the particular processing resources or capacities for which the two tasks compete. In a recent study, Wickens and Sandry (1980) investigated time-sharing efficiency effects attributed to the relation between the central processing capacities employed in two tasks and the controlling hand. According to the concept of task hemispheric integrality, (Wickens, Mountford, & Schreiner, 1981), a pair of tasks are more efficiently time-shared when (1) the processing of one task is spatial (right hemispheric) and the other is verbal (left hemispheric)[1], and (2) when the processing and response function of each task are both completed in one hemisphere (i.e., the spatial task is responded to with the left hand). In Wickens and Sandry's study This condition occurred when a tracking task, hypothesized to be right hemispheric and spatially processed was controlled with the left hand; while a Sternberg Memory Search task with letter stimuli, hypothesized to be left hemispheric and verbally processed was responded to with the right hand. A "mixture" condition was created with the opposite hand assignment (i.e., Sternberg task-left hand, tracking task-right hand). In this case, the processing function of one task and the response function of the other task are completed in the same hemisphere. Stated in other terms, the processing and response functions of a given task are distributed across hemispheres. Their results confirmed the hypothesis and replicated Wickens, Mountford, and Schreiner (1980), in that more efficient time-sharing was observed in the integrity than in the mixture condition.

In order to further validate their conclusions Wickens and Sandry (1980) also introduced a different form of the Sternberg task. It consisted of an "alphabet" of spatially-defined random 5-dot patterns which they inferred, when time-shared with tracking would provide no hand assignment that maintained integrity for both tasks. That is, using the spatial Sternberg stimuli, no matter how hands are assigned to tasks, one task would always be performed with "integrity," and the other in a mixed mode. The second study confirmed that overall time-sharing efficiency was unaffected by hand assignment since both tasks demanded processing resources from the same hemisphere, with either hand combination. Collectively, these results suggest that when the overloaded operator is confronted with two tasks--one spatial and one verbal--that must be time-shared, greater efficiency should result if the spatial control is operated with the left hand, while verbal responses are assigned to the right. If both are spatial, or both verbal, hand assignment should have little bearing, although one might expect the task requiring greater response precision to benefit from assignment to the next dominant hand.

While the prediction was confirmed concerning an integrity effect of hand assignment, a second prediction was not. This concerned the differential interference between the presumed spatial tracking task and the verbal and spatial variants of the Sternberg task. The spatial Sternberg task was assumed to demand similar resources as tracking, and therefore, to show greater interference. Such a prediction is based upon the delineation of processing resources in terms of spatial versus verbal codes of central processing (Baddeley & Lieberman, 1980; Wickelgren, 1979). Experimental evidence is available to suggest that two tasks that are spatial in their central processing demands will show greater mutual interference than a verbal and a spatial task, while a corresponding interference pattern may be shown with two verbal tasks (Brooks, 1967, 1968; Baddeley & Leiberman, 1980). Moscowitz and Klein (1980) observed spatial-spatial interference between two very dissimilar tasks: recognizing unfamiliar faces and line judging orientation.

Research summarized by Hicks and Kinsbourne (1978) suggest that this "code-specific" interference is hemispheric-defined, since the interference of a verbal task with tracking is greater when control of tracking is exercised with the right hand (sharing the same left hemispheric control center with the verbal task) than with the left. McFarland and Ashton (1978) observed that this hand advantage is reversed when a spatial memory task is employed instead of the verbal task.

Wickens & Sandry (1980) hypothesized that their failure to observe a main spatial-verbal effect may have resulted from the adoption of verbal coding strategy by some subjects in the spatial task when it was optimal for them to do so (i.e., when performing the Sternberg-right hand combination). Indeed Cohen (1979) has argued that laterality effects are sensitive to processing strategies involved. Verbal coding may have occurred despite the fact that the spatial stimuli were pretested to ensure that none could be easily verbalized and the subjects were discouraged from using a verbal strategy. The employment of this strategy is consistent with the observations of Umilta et al. (1978) that verbal (left hemispheric) processing was employed in processing familiar faces, and spatial (right hemispheric) processing for novel faces. It is also consistent with their findings of verbal (left hemispheric) processing for simple geometric figures and spatial processing for uncommon or complex ones.

The objective of the current investigation (actually three experiments), therefore, was to validate the spatial nature of the "spatial" Sternberg task through a task interference paradigm. In the first study (Experiment 1) a manipulation of Sternberg memory set size (1, 2, or 4 stimuli) was performed for each of the two forms of the Sternberg task. The effects of set size (N) were tested in order to be able to quantitatively compare the single task performance of each Sternberg form. A second goal of this experiment was to assess the degree of linearity of the Sternberg functions, and determine if the serial scan model postulated to underlie the processing of the verbal Sternberg tasks (Sternberg, 1969) holds with the spatial one as well.

The results of experiment 1 are utilized in a second study (Experiment 2) in which four tasks-a spatial tracking task,[2] a verbal word memorization task, and the two forms of the Sternberg task (spatial-verbal)-- were paired into a verbal-verbal, a spatial-spatial, and two verbal-spatial combinations. If the "spatial" Sternberg task is truly spatial in its demands, we assume that it will interfere to a greater extent with the tracking task than with the verbal task. However, to confirm that this differential interference, if obtained, does not simply result from a greater difficulty of the tracking task than the verbal task, we also compare the interference of the two Sternberg tasks when paired with the verbal memory task. In this case the interference pattern is predicted to be reversed.

Finally, in Experiment 3 we again contrast the two Sternberg tasks at different memory loads when paired with a dynamic system monitoring/failure detection task (Wickens, Kessel, 1980; Micalizzi & Wickens, 1980) to help identify the processing resource demands of that task, while iteratively informing us more about the nature of the Sternberg task differences.

Experiment 1: Effects of Set Size: Method

Subjects

Nine right-handed male subjects were employed on a voluntary basis to serve in this experiment. All subjects were students at the University of Illinois at Urbana-Champaign, had normal or corrected vision, and were paid $3.00/hour for their participation. Right handed male subjects were used because hemispheric specialization is most consistent in right handed subjects (Gross, 1972). The degree of right handedness was also evaluated for each subject using the inventory developed by Bryden (1977) to insure that the right hand was clearly dominant.

Apparatus

The two Sternberg tasks (spatial and verbal) were displayed on a Hewlett-Packard 8 x 10 cm 1300a CRT display. A Raytheon 704 sixteen bit digital computer with 24 K memory was used to generate the experimental displays and to record the subjects' responses from a spring-return pushbutton keyboard. The record of performance was stored on a Gould 4800 line printer for later analysis.

The subjects were seated in a sound and light attenuated booth. Positioned on a chair with two arm rests with interchangeable control keyboards, the subject sat directly in front of the CRT facing the screen. The distance of the controls was adjusted according to the length of the subjects' arm. The keyboard control had two 1 cm* pushbutton keys; one key was positioned higher and to the side of the other key. The viewing distance from subject's eyes to CRT was approximately 90 cm, subtending a visual angle of 5 degrees.

Task Description

Verbal Sternberg task. The verbal Sternberg paradigm required subjects to respond to series of visually presented letter stimuli as rapidly and accurately as possible. At the beginning of a trial, a fixed number of upper case letters (1, 2, or 4) appeared on the display for study. These letters, called the "memory" set, were drawn randomly from the alphabet, with the exception of the letter Q because of its great similarity to the letter O. A 10 second study period was provided before the display cleared. This was followed by a three minute test trial in which the series of letter stimuli were presented one at a time. The subject was required to make a positive response when the letter was a member of the memory set and a negative response if it was not. Subjects indicated their response by pressing the upper key with their middle finger for "yes" and the lower key with their index finger for "no." Following each response, a new stimulus was presented after a random interval from 3-5 seconds. Target probability was fixed at 0.5. The memory set size for each 3 minute trial (1, 2, or 4) was randomized within each subject and across all subjects. Reaction time and error percentage were recorded for performance measures.

Spatial Sternberg task. The spatial form of the Sternberg paradigm was identical in all respects to the verbal, with the exception of the stimulus material chosen. Instead of letters of the English alphabet, an alphabetized set of twenty four spatially defined, separate, and distinct random 5 dot patterns--adopted from Wickens and Sandry (1980)-- was selected (see Figure 1).

Experimental Design. A within subject design was employed in which each subject participated in all experimental manipulations for one session of practice and one session of data collection. The sessions each lasted one hour and took place on consecutive days. Subjects performed the twelve conditions in random order produced by this 2(Sternberg's stimuli) x 2(hand) x 3(set size) design. The 12 conditions were replicated once on both days; therefore, each session contained 24 single task trials which were randomized within and across all subjects.

Results: Experiment 1

The data from Experiment 1, plotted in Figure 2, show reaction time, for the two hand assignments (right vs. left) and the two stimulus types (spatial and verbal) for memory set sizes of 1, 2, and

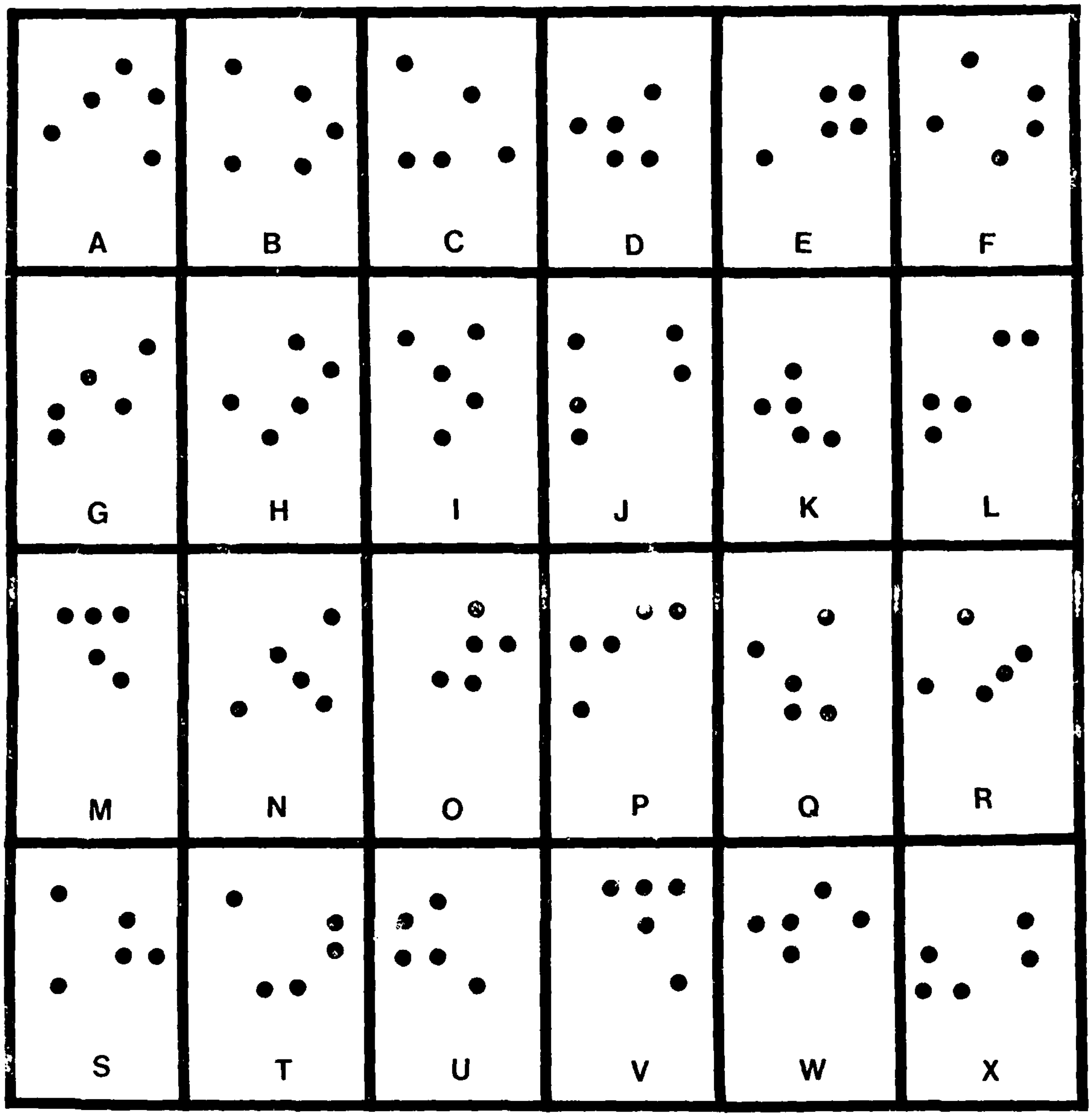

Figure 1: The Spatial Sternberg Stimuli: 5-dot patterns.

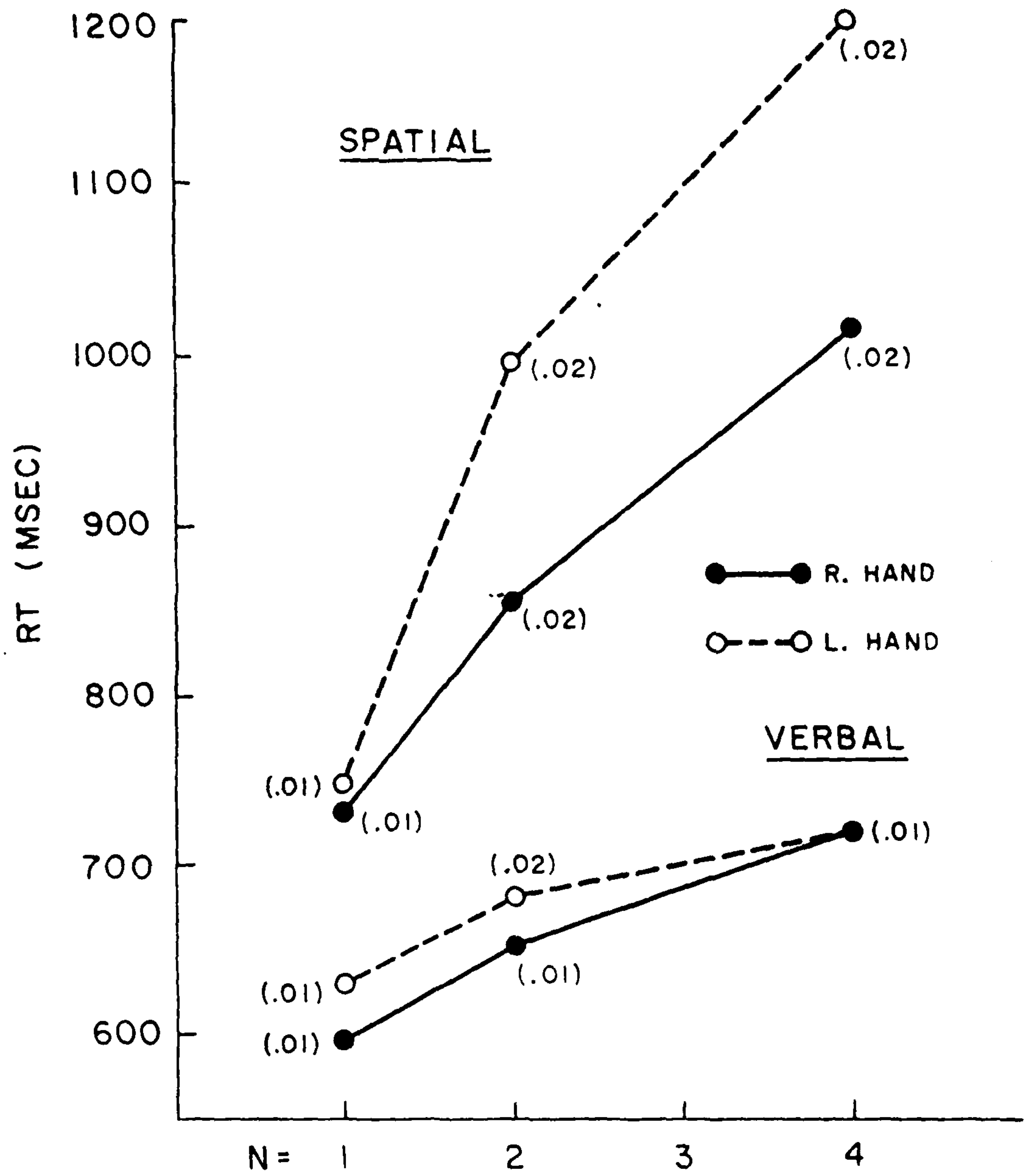

FIGURE 2: Effect of Memory Set Size and Response Hand on Reaction Time for Verbal and Spatial Sternberg Stimuli. (Error rates in parentheses.)

4. Error rates for the reaction time task are shown in parentheses. Since these generally correlated positively with RT, differences in RT are not apparently the result of a speed accuracy tradeoff.

Figure 2 suggests that RT performance is consistently faster with the verbal Sternberg task. A 4-way ANOVA (task (2) x hand(2) x N(3) x subject(9)) repeated measures ANOVA (Soupac Balanova program) was performed. A reliable main effect was found for task ($F_{1,8}$= 41.97; p < .001) indicating that the verbal Sternberg task was more rapidly performed than the spatial. The main effect for hand was also reliable ($F_{1,8}$= 10.74; p < .01) with right hand performance significantly faster than left for both the spatial and verbal task, as shown in Figure 2. This result is expected because only right-handed subjects were employed.

Reliable effects were observed for memory set size (N) ($F_{2,8}$ = 48.88; p < .01), and for the task x N interaction ($F_{2,8}$ = 11.11; p < .01). The latter interaction is reflected by the larger decrease in efficiency for the spatial, relative to the verbal task, as memory set size increased.

Analysis of linearity. Sternberg's (1969) character classification paradigm provided evidence that the scanning of human short term memory to determine if a stimulus probe is, or is not, contained in a memorized set of stimuli is both serial and exhaustive. This is typically indicated by a strong linear relationship between the response latency and the number of items in short term memory. In order to test for this linearity in both sets of data, a polynomial regression analysis was performed on the reaction times to determine the strength of the linear relationship between the RT and set size. For the analysis, between subject variability associated with the slope and intercept of the individual functions was eliminated by normalizing all subjects; data on the first and last points (i.e., for N = 1 the RT was set equal to 0 and for N = 4 the RT = 1). The middle point was then expressed as a proportion of the RT difference between these two points. In this manner, the degree of linearity could be determined by the position of the middle points. A stepwise polynomial regression analysis was employed.

For the verbal Sternberg RT data, with an N of 1, 2, and 4, the analysis indicated a strong linear relationship ($F_{1,24} = 73.36$; $p < .001$) which accounted for 74.58% of the variance. The addition of a quadratic component did not account for a significant amount of additional variance (that is, of 23.78% unexplained variance the quadratic model accounts for only 1.74% of this, with an $F_{2,24} = 1.77$). Thus, it is safe to accept the hypotheses that the relationship is linear, and that the small negative acceleration evident in Figure 1 is not due to the contribution of a significant quadratic trend.

For the spatial stimuli with N of 1, 2, and 4, the analysis again indicated a strong linear relationship ($F_{1,24} = 91.29$; $p < .001$) which accounted for 78.5% of the variance. The addition of the quadratic component ($F_{2,24} = 4.32$; $p < .05$) accounted for an additional 3.28% of unexplained variance. That is, the data analysis indicated a strong linear relationship with a marginally reliable quadratic component accounting for the negative acceleration of the function in Figure 1. The reliable negative acceleration with the spatial stimuli suggests that the processing of the spatial stimuli may reflect the logarithmic relation between RT and set size expressed in the Hick-Hyman Law (Hick, 1952). Accordingly, a log transform was performed on the set size variable, thereby producing abscissa values in Figure 2 of 0 (Log 1), 1 (Log 2), and 2 (Log 4). A second polynomial regression analysis was performed on these data.

For the verbal Sternberg task, the reanalysis again indicated a strong linear relationship ($F_{2,24}$ = 80.10; $p < .001$) which accounted for 76.21% of the variance. The addition of a quadratic component did not account for a significant amount of additional variance ($F_{1,24} <$ 1.0). For the spatial polynomial regression, the reanalysis also showed a strong linear relationship ($F_{1,24}$ = 112.16; $p < .001$) which accounted for 81.77% of the variance. Again, the addition of the quadratic component did not account for a significant amount of additional variance. Of 18.23% unexplained variance only .01% is explained by the addition of the quadratic model ($F_{2,24}$ = .014).

The combined results of these analyses suggest that the fit of the verbal Sternberg data is little improved by the log transformation (74.6% vs. 76.2% of the variance). The amount of improvement in the linear fit of the spatial data is somewhat greater. The linear component accounted for 78.5% of the variance when plotted as a function of N, and for 82% when expressed as a function of Log N. It is not clear whether this improvement is great enough to reject the serial scan (and linear slope with N) model proposed by Sternberg (1969) when the spatial stimuli are employed. We adopt the position here that the serial scan model is still valid (given the 78% of variance accounted for). We argue that the small quadratic component is attributable not to an abandonment of the linear search strategy by the subjects but to a lowering of the N = 1 point. The single stimulus in this condition may allow subjects to use a slightly different strategy of comparison from that employed when N = 2 and N = 4.

Laterality effect. While the primary intent of experiment 1 was to evaluate the relationship between set size and RT for the two Sternberg stimuli, an additional effect in the ANOVA provides some evidence concerning the cerebral localization of processing the two stimuli. This effect is manifest in the reliable three-way (hand x task x N) interaction that was obtained ($F_{2,8} = 3.35$; $p = .06$). This interaction suggests that with the spatial task the advantage of using the right hand increases with task load while with the verbal task the advantage of the right hand decreases with memory load.

Graphically in Figure 2, the two hand curves diverge with N increase for the spatial task, but converge with the verbal task. These results are consistent with the assertion that the verbal and spatial stimuli are processed partially in separate cerebral hemispheres, and that the processing resources in the two hemispheres are to some extent independent (Alwitt, 1978; Kinsborne & Hicks, 1978; Wickens, 1980). Wickens and Sandry (1980) have argued that in single task reaction time performance, there will be a cost associated to the extent that the hand of response is controlled by the hemisphere that is processing the stimulus. This cost reflects the competition for resources between stimulus processing and response organization within a given hemisphere (Dimond & Beaumont, 1972; Green & Well, 1977; Alwitt, 1981).

Accordingly, as the processing is rendered more difficult, the cost should be amplified. In the present data, for the spatial stimuli assumed to be processed in the right hemisphere, we note the cost, as the slower left handed (right hemisphere) response when the right hemisphere is also engaged in processing the spatial stimuli. As the load of processing increases (via increasing N), the cost increases and the two functions diverge. For the verbal task, the cost of the right handed (left hemisphere) response to processing the verbal (left hemisphere) stimuli is balanced by an intrinsic right (dominant) hand advantage. However, this benefit is attenuated by an increasing cost, as predicted by the model, as the memory load placed upon left hemispheric processing increases with N. Thus the two functions converge rather than diverge with memory load.

Experiment 2: Validation of Resource Demands of the Spatial Sternberg Task: Method

Subjects

Eight subjects with characteristics identical to those of Experiment 1 were employed in Experiment 2.

Apparatus

Details of the apparatus were very similar to those of Experiment 1; however, certain changes should be noted. In addition to the Sternberg tasks, a tracking task was displayed. In this task the subjects' responses from the control stick were again processed by the Raytheon 704 and the record of performance (RMS tracking error) was stored for later analysis. Each task (Sternberg and tracking) was programmed so that the subject could perform it with the left or right hand as the controls were interchanged between arm rests. When the two tasks were performed simultaneously, the Sternberg stimulus (verbal or spatial) was presented immediately below (1.5 degrees of visual angle) the zero error reference of the tracking display.

Task Description

Sternberg task. The two Sternberg tasks were identical to those described in Experiment 1 with the exception that the memory set size (N) was at a fixed level of two for the spatial Sternberg task and four for the verbal. These values were chosen in an effort to reduce the discrepancy between RT's in the two task. It was recognized, on the basis of the data from experiment 1, that these values would still provide a substantial advantage to the verbal task (see Figure 2). However, given the possible qualitative difference in processing in the N = 1 condition contrasted with the multiple N conditions, our decision was not to employ this condition for the spatial task, and instead to tolerate a difference of approximately 200 msec between the single task RT's.

Tracking task (spatial). The one-dimensional tracking task required the subjects to nullify an error cursor that was displaced horizontally by a random noise forcing function with a cutoff frequency of .40 Hz. Subjects controlled the error cursor by applying force with the right hand to a spring-loaded joystick which moved in a left-right direction. The control dynamics of this task were of first order, of the form $Y = \frac{k}{s}$ or $O(T) = K \int I(T)\, dT$. That is, the cursor position moved with a velocity proportional to the displacement of the subject's control stick. Root mean square (RMS) error was recorded as a performance measure.

Word memorization task (verbal). The word task required the subjects to memorize a verbally presented list of six words of low imagery value. At the beginning of a trial, the experimenter read a list of six words to the subject. These words were carefully selected to ensure that none could be easily visualized, thus increasing the likelihood of a verbal, rather than an imagery related coding strategy (Paivio, 1975; Klee & Eysenk, 1976). Random lists each with six-low imagery nouns were generated using the 104 words with the lowest of the "imagery ratings" on norms developed by Paivio, Yuille, and Madigan (1968) for 925 nouns ("lowest" here was defined as a value less than 3 on a scale of 1-6 in which 1 means "arouses an image not at all"). After a three-minute test trial subjects were asked to verbally recall the six words. As a performance record, errors were recorded when the subjects incorrectly recalled a word or failed to recall a word at all. The memory set for each three-minute trial was randomized within each subject and across all subjects. See Appendix A for a list of the 104 nouns chosen.

Experimental Design

A within subject design was employed in which each subject participated in all experimental manipulations over one session of practice and two sessions of data collection. Each session lasted one hour and took place on consecutive days.

Each session contained 16 trials: two replications of each of the 4 single task conditions (spatial and verbal Sternberg, tracking, and word task, 8 trials), 2 dual task verbal Sternberg conditions (one paired with tracking and one paired with the word task), each replicated (4 trials); and 2 dual task spatial Sternberg conditions, one paired with tracking and one paired with the word task, each replicated (4 trials). All 16 trials were randomized within and across all subjects. Experimental instructions designated the tracking and verbal memory tasks as primary, so that variance due to task interference would be associated with the Sternberg task.

Results: Experiment 2

Shown in Figure 3 are the reaction times for the spatial (top) and verbal (bottom) Sternberg tasks under the single task and each of the two dual task conditions. The overall superiority of the verbal task (faster RT) is evident, despite the greater memory set size (4 vs. 2) that was employed. This difference of approximately 150 msec was anticipated on the basis of the data from experiment 1. The average magnitude of the decrement from the single to the two dual task conditions appear to be roughly equivalent across the two Sternberg conditions. In fact, numerically the magnitude of the average decrements are only 5 msec different between the two stimulus types (verbal: 63 msec, spatial: 68 msec).

Of greatest importance to the hypothesis under consideration is the differential effect of the two different loading tasks: tracking and verbal memory on performance of the two Sternberg tasks. The spatial Sternberg task was disrupted more by tracking, whereas the verbal Sternberg suffered more in the presence of the memory task. (The error rates, shown in parentheses beside each point, correlate

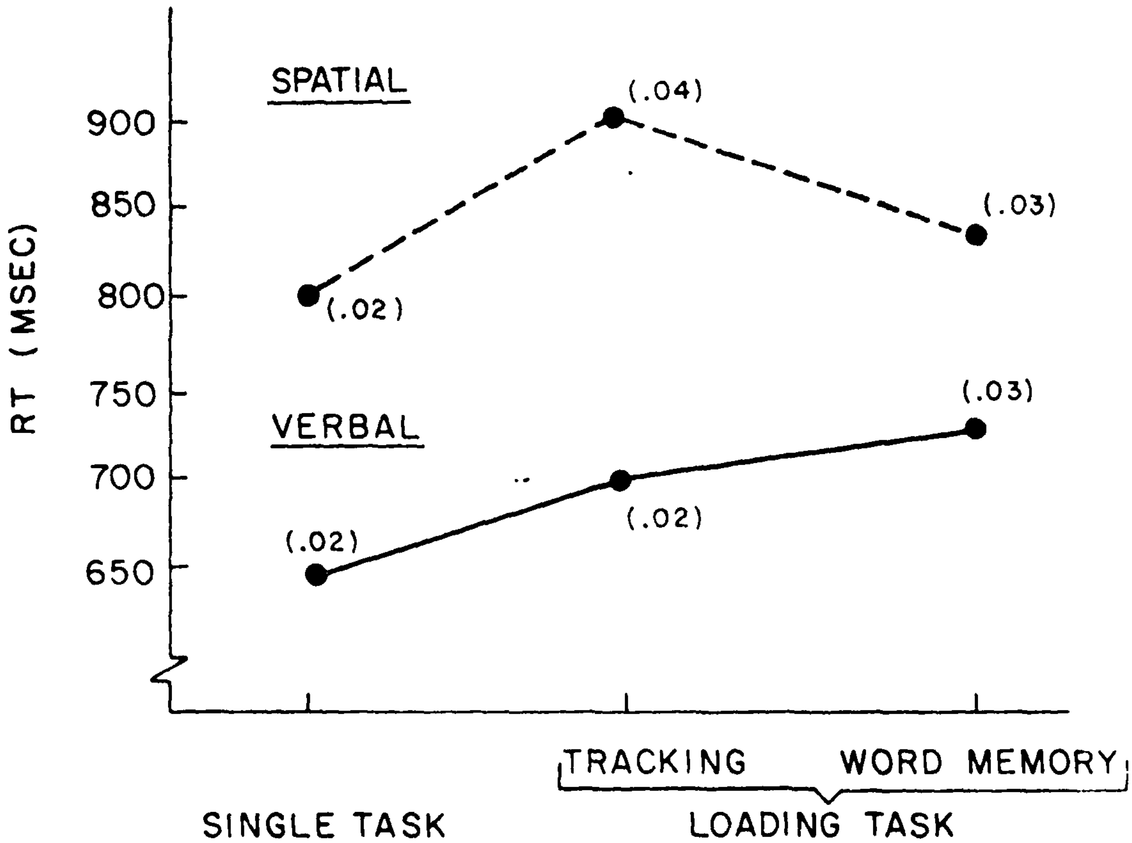

FIGURE 3: Effect of Dual Task Load on Spatial and Verbal Sternberg Reaction Time.

positively with RT and therefore suggest that these effects are not the result of a speed-accuracy tradeoff.) The reliability of this interaction was tested by a 2(Sternberg task) x 2(loading task) repeated measures ANOVA conducted on the dual task data. As expected, a reliable main effect of Sternberg task was obtained indicating the verbal superiority ($F_{1,}$ = 59.[illegible]0, p < .001). While the loading task factor did not exert a reliable effect, (F < 1.00), the critical loading x Sternberg task interaction was statistically reliable ($F_{1,}$ = 8.[illegible]0, p < .02).

In a secondary task paradigm such as that employed here it is essential to demonstrate that variance in secondary task performance (i.e., Sternberg RT), reflects variance in resource competition, and not the differential allocation of resources between the primary and secondary tasks, that is, conditions of better secondary task performance should not show relatively worse primary task performance. Fortunately, in the present data, such a tradeoff was not in evidence. Tracking RMS error scores obtained concurrently with the spatial and verbal Sternberg tasks were 0.233 and 0.228, a difference that was not statistically reliable (F = 1.3, p > .10). Correspondingly, the difference in the percentage of words missed in the verbal task between the two Sternberg conditions was also not statistically reliable (F < 1.0). Thus the results support the conclusion that the spatial Sternberg task shared more common resources with tracking, and the verbal task shared more resources with the memory task.

Experiment 3. Method

In experiment 3, subjects performed the spatial and verbal variants of the memory search task at each of two levels of memory load, concurrently with a monitoring/failure detection task, identical to that employed by Micalizzi and Wickens (1980).

Subjects

Eight right-handed male students from the University of Illinois participated in all experimental manipulations. All had normal vision and were paid $2.50 per hour plus additional bonuses based on performance.

Tasks

Failure detection. This task required subjects to monitor an autopilot that controlled a single axis pursuit tracking task. At unpredictable times during each 2 minute trial, a failure would occur (the experimenter would select 4, 5, or 6 failures per trial). The failure resulted in a ramp change in system dynamics from 1st to 2nd order and subjects were instructed to respond as quickly as possible by pressing the trigger with their left hand when they thought a failure had occurred. The computer recorded hits, misses, false alarms, and hit latencies. If a failure was detected, system dynamics were immediately reset to pre-failure level. Otherwise, the failed condition lasted 10 seconds and then the dynamics returned to pre-failure conditions by a smooth 4 second ramp. Failures appeared as a gradually growing series of unstable oscillations superimposed on the autopilot's purposeful corrections of the error. An analogous task of this type had been previously demonstrated by Wickens & Kessel (1980) to demand primarily perceptual/central processing resources.

Sternberg task. The two versions of the Sternberg task were identical to those employed in experiments 1 and 2. However, in contrast to experiment 2, two levels of memory load were employed: spatial (N = 1 & 2); verbal (N = 2 & 4). The low and high memory load conditions for each version are referred to as "easy and difficult", respectively.

Design

Each subject participated in all experimental manipulations: single vs. dual task, verbal vs. spatial stimuli, and easy vs. difficult Sternberg conditions. All subjects participated in 5, one hour daily sessions, consisting of one day of practice and four days of data collection. Spatial and verbal manipulations were administered on different days and the specific sequence of spatial vs. verbal days for each subject was counter-balanced to avoid the bias of any particular sequence.

Procedure

On any particular experimental day, each subject was exposed to 2 single task failure detection trials, 8 single task Sternberg trials (4 easy Sternberg x 4 difficult Sternberg), and 8 dual task trials (4 easy Sternberg and 4 difficult Sternberg). These trials were administered in 4 alternating blocks of dual vs. single task trials. Each trial lasted 2 minutes.

Experimenter instructions designated failure detection as the primary task, emphasizing that dual task performance should equal single performance. The secondary Sternberg task performance should therefore reflect changes in resource competition between tasks. A bonus system reinforced these instructions. The failure detection bonus depended on hit latency and was halved if one false alarm occurred. Two false alarms resulted in eliminating the failure detection bonus altogether. The Sternberg bonus was contingent on acceptable primary task performance (dual task = single task), and based on reducing RT below the previous day's single task RT.

Results and Discussion: Experiment 3

Primary task (failure detection) performance remained constant across all conditions. There was no reliable effect of conditions on either detection latency or accuracy (all F's < 1.00), so that the effects due to resource competition were clearly partialled into the secondary task.

The reaction time data from the two versions of the Sternberg task are shown in Figure 4. In the following discussion, the significance of the statistical effects is based upon a 2(task:verbal/spatial) x 2(task load:single/dual) x 2(memory load) repeated measures ANOVA performed on the RT data. From the data in Figure 4 it is evident that the two tasks competed for common resources. Reaction time in both the verbal and spatial condition was slower in dual, as opposed to single task conditions ($p < .001$). In addition, both were affected by the memory load manipulation ($p < .001$), and spatial RT's were somewhat more prolonged ($p < .01$), than verbal.

Of the three 2-way interactions between the 3 variables, two were statistically reliable. (1) The effect of memory load on RT was greater for the spatial, than for the verbal task, replicating the result obtained in experiment 1 ($p < .01$). (It should be noted that

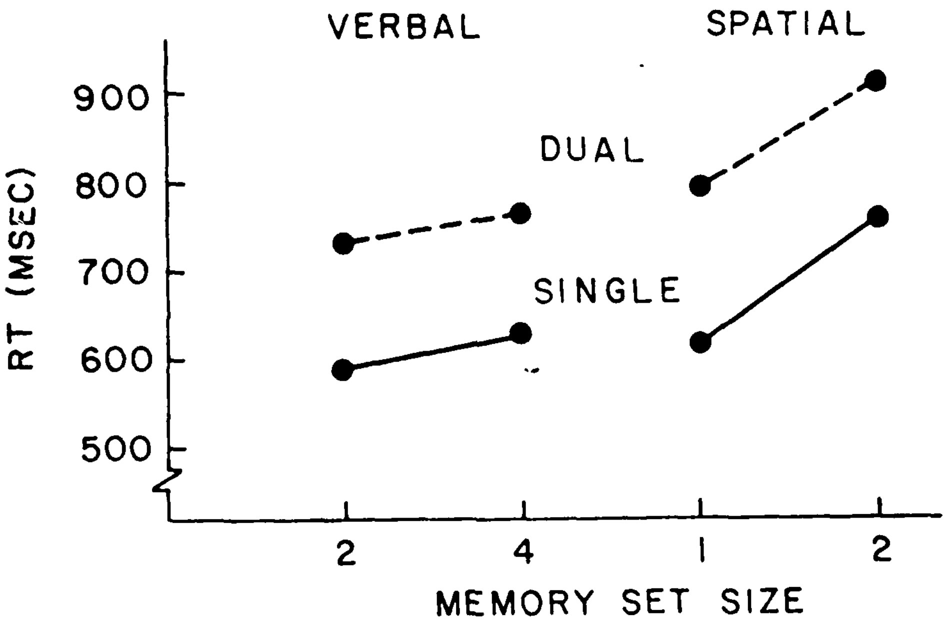

FIGURE 4: Effect of Concurrent Failure-detection Task and Memory Set Size on Verbal and Spatial Sternberg Reaction Time.

part of this effect may reflect the fact that values of N = 1 & 2 were used for the spatial task, and N = 2 & 4 for the verbal. The data of Figure 2 suggest that this choice places the spatial stimuli at a steeper portion of the function than the verbal stimuli since the N = 1 point may be artifactually lowered). (2) The effect of dual task loading was greater for the spatial than the verbal task ($p < .01$). However, the third 2-way interaction between the three variables was not statistically reliable. That is, the influence of memory load was additive with dual task load. Furthermore, the three-way interaction was also not significant: the two graphs within each panel of Figure 4 are both statistically parallel. Error rate was found to correlate positively with latency, so that the obtained effects are not attributable to the operation of a speed- accuracy tradeoff.

Two aspects of the results are worthy of note in light of previous findings in our laboratory employing similar designs. (1) The absence of an interaction between dual task load and memory load is seemingly in contrast with a resource competition hypothesis. According to the multiple resource interpretation proposed by Wickens (1980; Wickens & Derrick, 1981; Micalizzi & Wickens, 1980), the memory search operation and failure detection task should both compete for the common resources underlying perceptual and central processing activities. Therefore, one variable should be predicted to magnify the other's effect. That such a positive interaction was not obtained for either Sternberg variant however, is consistent with a number of previous observations in the literature in which the relation between memory set size and the presence or absence of a primary task has been found to be either additive (Briggs, Peters, & Fisher, 1972; Griffeth & Johnston, 1977), or underadditive[3] (Crawford, Pearson, & Hoffman, 1978; Spicuzza, Pincus, & O'Donnel, 1974; Wickens & Derrick, 1981) (see Micalizzi & Wickens, 1980 for a summary). Generally speaking, an interactive effect with memory set size appears primarily to be observed exclusively with an increase in primary task load as was observed by Wickens & Derrick (1981) and not with the presence or absence of the primary task. The investigation of Logan (1978) appears to provide the sole exception to this rule. He noted an interaction between set size and the presence or absence of a short term memory task.

(2) The greater effect of the failure detection task requirement on the spatial, as opposed to the verbal Sternberg task is consistent with the hypothesis that the process of monitoring the dynamic system requires at least some non-verbal resources, functionally separate from the resources employed in the verbal Sternberg taks. This hypothesis would also predict that the influence of memory load should be amplified under dual task conditions with the spatial, more than with the verbal stimuli. As noted, however, this amplification would be manifest in the 3-way interaction between set size, loading task, and task load, an effect which was not reliable. Perhaps its failure to occur is another manifestation of the general additivity that seems to occur between the presence or absence of a primary task and memory set size.

General Discussion

The current set of three experiments illuminated the similarities and differences between the spatial and verbal variants of the Sternberg Memory Search Task used in the research paradigms described by Wickens and Sandry (1980), Micalizzi and Wickens (1980), and Wickens and Derrick (1981). In particular, an assumption of Wickens and Sandry's investigation of task hemispheric integrity was that processing of the spatial and verbal stimuli were right and left hemispherically lateralized, respectively.

The data from experiment 1 suggest that a common serial search mechanism described by Sternberg (1969), underlies the processing of both stimuli in the memory search paradigm. There is, however, a suggestion of possible non-serial processing in the spatial task, producing the non-linear source of variance. Nevertheless, the data are best fit by assuming the linear model. The search process appears to take place at a somewhat slower rate for the spatial, than for the verbal stimuli, as would be predicted by the lesser degree of familiarity with the former material. Figure 2 suggests these search rates to be approximately 33 msec/character (verbal) and 120 msec/charcter (spatial). The verbal rate is quite close to the 38 msec/character rate obtained by Sternberg (1969, 1975).

The most important implication of the data from experiment 1 with regard to Wickens and Sandry's (1980) study concerns the pattern of the interaction between set size, hand of control, and stimulus material. This interaction is consistent with a model that localizes the processing of the spatial and verbal stimuli in the right and left cerebral hemispheres, respectively, and predicts increasing interference when the control center for a response hand, competes for hemispherically-defined resources with an increasingly difficult (i.e., higher N) memory search. The general effects of competition for resources between processing and response functions of a given task within a cerebral hemisphere has been observed as well in studies by Alwitt (1981), Green and Well (1977), and Dimond and Beaumont (1972).

This pattern of results is quite consistent with the data of experiment 2. Here a "crossover interaction" of task interference was obtained between the Sternberg task (spatial-verbal), and the primary loading task (tracking vs. abstract verbal memory). This pattern of interactions between spatial and verbal interference is similar to those observed previously by Brooks (1967, 1968), Klee and Eysenk (1973), and by Baddeley and Lieberman (1980), and is used to support the concept of hemispherically-defined resources (Kinsbourne & Hicks, 1978; Wickens, 1980). With regard to the two primary tasks used here, considerable behavioral and clinical data would allow the inference that the memory of abstract words tends to be left hemispherically localized (Moscowitz, 1979; Deutch & Springer, 1981). The patterns of data obtained by Baddeley and Leiberman (1980), Wickens and Sandry (1980) and Wickens, Mountford, and Schreiner (1981) indicates that the processing underlying tracking is somewhat right-lateralized. Assuming this partial lateralization of the two primary task employed in experiment 2, the crossover interaction then implies that the processing of the two Sternberg tasks are lateralized as well.

The results of experiment 3 neither confirm nor disconfirm the pattern of relations revealed in experiments 1 and 2. Instead, this pattern of relations is used to help explain experiment 3's results.

The greater effect of failure detection on the spatial, as opposed to the verbal Sternberg task, confirms the spatial processing, possibly hemispherically defined, that underlies the failure detection task. As noted, the lack of an interaction between the dual task set size effect and the spatial/verbal material is not readily interpretable in terms of resource competition.

In summary, the present data continue to provide evidence that the spatial/verbal dichotomy is one with important implications for dual task interference and has a clear anatomical (i.e., hemispheric) basis. Furthermore, the use of the two variants of the Sternberg task represents a possible tool for probing this dichotomy with tasks whose degree of lateralization is not firmly established. The practical importance of this dichotomy for the area of task integration and workload measurement seems to be two-fold: (1) It offers an explanation of the surprising degree of efficiency with which verbal and spatial (e.g., tracking) tasks can often be time-shared (Wickens, 1980). (2) It reinforces a principle of maximum secondary task similarity. In the present case, when quantitative differences in the workload of a spatial (verbal) task are to be measured. This principle asserts that greater sensitivity of a secondary task workload measure will be obtained when that task is also spatial (verbal), than when the converse relation is employed (Wickens, 1980b). When, instead, the secondary and primary tasks employ different codes (e.g., one is spatial, the other verbal), workload differences are likely to be underestimated.

As a practical example, assume the workload difference between two tracking display configurations are to be compared. Since the task is spatial (tracking), greatest sensitivity will be observed when a spatial, rather than a verbal Sternberg task is employed. This does not imply that the verbal task will be insensitive to tracking workload differences. Research by Schiflett (1980) and by Wickens and Derrick (1981) have demonstrated that the alphabetic (verbal) Sternberg task will reflect differences in manual control workload. However, there is an increased likelihood in this case that the variance attributable to random factors will dominate the relevant variance attributable to resource competition, and statistically reliable effects will then not be observed.

A final conclusion drawn from the present investigation and seemingly supported by the large amount of converging data from other studies concerns the additivity observed between set size and the presence or absence of the primary task. While memory set size is assumed to vary the load imposed upon perceptual-central processing resources, it seems reasonable to conclude that the failure to observe an interaction between the set size variable and the presence of a primary task does not allow the investigator to conclude that the primary task has neither perceptual nor central processing demands. Such a conclusion would be unwarranted in light of the data such as those reported in experiment 3, in which the failure detection task is clearly perceptual (see also Micalizzi & Wickens, 1980), yet additivity is observed. The possible reasons for additivity in this case are discussed in greater detail by Wickens and Derrick (1981) and by Logan (1978) and seem to be related more to the automaticity of certain processes, than to the structure of processing resources.

Footnotes

[1]Recent evidence suggests that the spatial-verbal distinction may well be associated with the right and left cerebral hemispheres, respectively, in approximately 95% of the adult population (Moscowitz, 1979) (practically all right-handed individuals, and roughly 50% of the left-handed populations).

[2]In several other studies the tracking task has been assumed to be spatial in nature, and therefore, to place its central processing demands upon the right hemisphere (Wickens, Mountford, & Schreiner, 1979).

[3]*The magnitude of the set size effect is diminished in dual, relative to* single task conditions.

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Appendix A

The following is a list of the 104 nouns used in Experiment 2 for the word task which were extracted from a list of 925 nouns developed by Paivio, Yuille, and Madigan (1968). The nouns chosen were those rated with an imagery value less than 3 on a scale of 1-6, in which 1 meant "arouses on image not at all." This ensured that the word task was not easily visualized and was, in fact, verbal in nature.

104 Nouns Rated Low in Imagery Value (< 3.0)

Abasement
Abbess
Aberration
Ability
Adage
Advantage
Adversity
Afterlife
Allegory
Amount
Answer
Aptitude
Arbiter
Attitude
Attribute
Banality
Belief
Blandness
Causality
Chance
Clemency
Comparison
Competence
Concept
Context
Criterion
Dalliance
Debacle
Deduction
Democracy
Disclosure
Discretion
Disparity
Disposition
Distinction
Ego
Elaboration
Emporium
Encephalon
Equity
Essence
Event
Exactitude
Exclusion
Excuse
Explanation
Facility
Fact
Fallacy
Fate
Fault
Figment
Foible
Folly
Forethougth
Franchise
Functionary
Gender
Gist
Hankering
Hint
Hypothesis
Idea
Impropriety
Inanity
Incident
Increment
Inducement
Ingratitude
Instance
Intellect
Interim
Irony
Knowledge
Magnitude
Mastery
Method
Misconception
Moment
Occasion
Origin
Osculation
Outcome
Permission
Position
Proxy
Rating
Reminder
Replacement
Simile
Situation
Soul
Supplication
Suppression
Surtax
Temerity
Tendency
Theory
Thought
Truth
Unbeliever
Unification
Unit
Unreality

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